

(19) World Intellectual Property
Organization
International Bureau



533349

(43) International Publication Date
13 May 2004 (13.05.2004)

PCT

(10) International Publication Number
WO 2004/040722 A1

(51) International Patent Classification⁷: **H01S 5/068**

(21) International Application Number:
PCT/IE2003/000148

(22) International Filing Date: 30 October 2003 (30.10.2003)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
S020846 30 October 2002 (30.10.2002) IE

(71) Applicant (for all designated States except US): **INTUNE TECHNOLOGIES LIMITED** [IE/IE]; 9C Beckett Way, Park West Business Park, Dublin 12 (IE).

(72) Inventors; and

(75) Inventors/Applicants (for US only): **FARRELL, Tom** [IE/IE]; 9C Beckett Way, Park West Business Park, Dublin 12 (IE). **MCDONALD, David** [IE/IE]; 9C Beckett Way, Park West Business Park, Dublin 12 (IE). **MULLANE, Thomas** [IE/IE]; 9C Beckett Way, Park West Business Park, Dublin 12 (IE).

(74) Agents: **LANE, Cathal, Michael et al.**; Tomkins & Co., 5 Dartmouth Road, Dublin 6 (IE).

(81) Designated States (*national*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

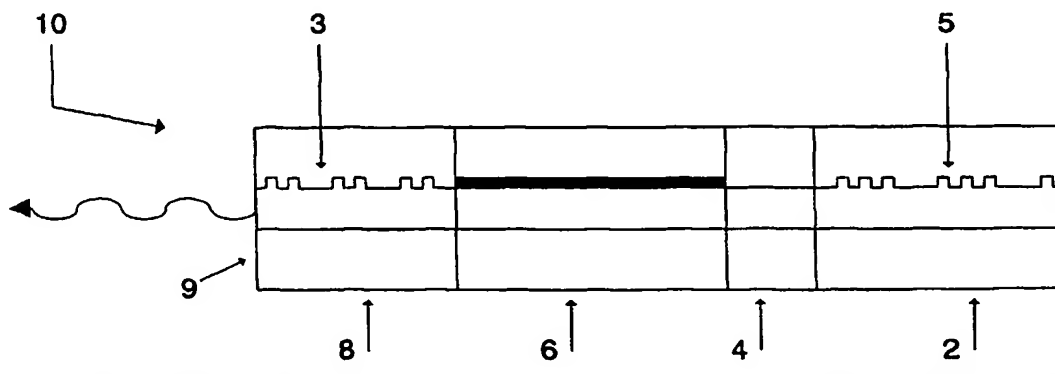
(84) Designated States (*regional*): ARIPO patent (BW, GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

- with international search report
- before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: **METHOD FOR COMPENSATION OF DEGRADATION IN TUNABLE LASERS**



(57) Abstract: The invention provides a method to compensate for degradation in a tunable laser and ensure its performance by tracking the degradation and adjusting the control information accordingly. This is accomplished by performing some measurements of the output of the tunable laser at an initial setup or calibration procedure. Then, by effecting a periodic repetition of these measurements and using a comparison between these two measurements the present invention provides for a compensation factor for the operating conditions, primarily in the form of a look up table of operating points of the laser. These measurements show how much the operating points of the laser have drifted over the period since the last set of measurements, which provide control information to compensate for degradation in the laser.

WO 2004/040722 A1

Title

Method for compensation of degradation in tunable lasers

Field of the Invention

5

This invention relates to tunable lasers and a method to compensate for the degradation of the tunable lasers. This invention specifically relates to a method to detect changes in the structure of the laser which may lead to changes in the output performance of the laser and a method to compensate the control information to compensate for these effects so that the output of the laser remains constant despite the degradation.

15 Background to the Invention

Multi section laser diodes are well known in the art and can be switched between different wavelengths. Typically the diode is calibrated at manufacture to determine the correct control currents that should be applied to the laser so as to effect the desired output frequencies from the laser. Degradation in a tunable laser is normally due to dislocations or changes in the material structure of the laser which leads to less injected carriers entering the cavity of the laser and instead passing through the regions surrounding the cavity. These injected carriers that no longer enter the cavity have the effect of reducing the efficiency of the laser as these carriers can no longer contribute to changing the output of the laser.

One of the first known multi-section laser diodes is a three-section tuneable distributed Bragg reflector (DBR) laser. Other types of multi-section diode lasers are the sampled grating DBR (SG-DBR), the superstructure sampled DBR (SSG-DBR) and the grating assisted coupler with rear

sampled or superstructure grating reflector (GCSR). A review of such lasers is given in Jens Buus, Markus Christian Amann, "Tuneable Laser Diodes" Artech House, 1998 and "Widely Tuneable Semiconductor Lasers" ECOC'00.

5 Beck Mason.

Figure 1 is a schematic drawing of a typical SG-DBR 10. The laser comprises of back and front reflector sections 2 and 8 with an intervening gain or active section 6 and phase section 4. An anti-reflection coating 9 is usually provided on the front and rear facets of the chip to avoid facet modes. The back and the front reflector take the form of sampled Bragg gratings 3 and 5. The pitch of the gratings of the back and front reflector vary slightly to provide a vernier tuning effect through varying the current supplied to these sections. The optical path length of the cavity can also be tuned with the phase section, for example by refractive index changes induced by varying the carrier density in this section. A more detailed description of the SG-DBR and other tuneable multi-section diode lasers can be found elsewhere Jens Buus, Markus Christian Amann, "Tuneable Laser Diodes" Artech House, 1998.

25 As detailed above such tunable semiconductor lasers contain sections where current is injected to control the output frequency, mode purity and power characteristics of the device. Various applications in telecommunications/sensor fields require that the laser can operate at points in a predetermined frequency/wavelength grid; moreover many applications require the power output of the device to be within a defined tolerance for each operating point, and in general, the operating points must be distanced from mode jumps and have high side-mode suppression. In order to provide lasers for such applications, each individual

device must be characterised to the desired specification, so there is a corresponding need for a system or algorithm to map the output of the laser over a range of operating currents. For characterisation of
5 lasers in production environments, such a system must also be fast, reliable and automated.

When the calibration is completed a set of operating points are obtained where each operating point
10 corresponds to a required frequency of operating of the laser. The problem exists that as the laser degrades the characteristics of the laser will change relative to this set of operating points and a method to update the table to take these changes into account is required. This
15 invention describes a method where this can be achieved.

Object of the invention

The object of the present invention is to provide a
20 method to compensate for degradation in a tunable laser and ensure its performance by tracking the degradation and adjusting the control information accordingly.

Summary of the Invention

25 Accordingly the present invention, as set out in the appended claims, provides a method adapted to monitor degradation in tunable lasers and a means to adjust the operating conditions of the laser to compensate for these
30 effects. This is accomplished by performing some measurements of the output of the tunable laser at an initial setup or calibration procedure. Then, by effecting a periodic repetition of these measurements and using a comparison between these two measurements the
35 present invention provides for a compensation factor for

the operating conditions, primarily the look up table of operating points of the laser.

5 These measurements show how much the operating points of the laser have drifted over the period since the last set of measurements. These measurements typically involve one or more of the following steps:

10 setting the gain section of the laser to a predetermined fixed value;
 10 setting all the tuning sections currents of the laser to zero;
 in turn ramp each tuning section from zero to a specified value and measuring the output power / etalon response of the laser during the ramp and
15 setting the tuning section current back to zero.

By having each of the other tuning sections at zero while the measurement is performed, this allows degradation to be measured independently in each section of the laser.
20

After a specified period of time or when some alarm condition has been reached the measurements specified above are re-measured and compared to the initial measurements. In a first embodiment the location of mode
25 jumps in the laser is the key attribute to examine, but wavelength and/or other parameters can also be considered.

Using the embodiment of examination of the location of the mode jumps it will be appreciated that by examining the differences in the position of the mode jumps a transform function can be calculated to convert the re-measured mode jump positions to the same position as the initial mode jump positions.
30

35

This transform function is then used to convert the lookup table of operating points to adjust them for the degradation in the laser.

- 5 There is also provided a computer program comprising program instructions for causing a computer program to carry out the above method which may be embodied on a record medium, carrier signal or read-only memory.

10 Brief Description of the drawings

These and other features of the present invention will better understood with reference to the following drawings wherein :

15

Figure 1 shows a schematic of a Sampled Grating Distributed Bragg Reflector Laser diode (SG-DBR).

- Figure 2 shows a graph of an initial set of measurements from the laser showing the results from the front tuning section of an SG-DBR laser.
- 20

- Figure 3 shows a graph of a set of measurements from the laser after degradation has occurred showing the results from the front tuning section of an SG-DBR laser.
- 25

Figure 4 shows the measurement in figure 3 overlaid on figure 2.

- Figure 5 shows the measurement in figure 3 overlaid on figure 2 where the data in figure 3 has been converted by a transform function so that the position of mode jumps overlaps.
- 30

35

Detailed Description of the Drawings

The invention will now be described with reference to exemplary embodiments thereof and it will be appreciated
5 that it is not intended to limit the application or methodology to any specific example, but rather can be applied to any tunable laser. The techniques used by the method of the present invention are specifically provided to enable the measurement of degradation and a means to
10 compensate for this effect.

Initially a set of measurements are performed on the laser that show the positions of mode jumps in the laser for each section of the laser where the other tuning
15 section currents are set to zero. An example of such a measurement output is shown in Figure 2.

These measurements are performed by:

- 20 (a) setting the gain current of the laser to a specified predetermined value. This value may, for example, be the average gain current of the operating points in the lookup table.
- (b) setting the tuning currents of the laser to zero.
- 25 (c) measuring the output power / etalon/ wavelength of the laser while the current of one tuning section is increased and while the currents in all other tuning sections is set to zero, and
- 30 (d) repeating the above measurement for all tuning sections of the laser.

The above measurement provides a first or reference measurement at time zero when no degradation has occurred
35 in the laser. This measurement is shown in Figure 2.

When degradation has occurred in the laser after a specified time of operating, or when some alarm condition has been triggered the above measurement may be repeated. An example of such a measurement set as determined at a later period is shown in Figure 3.

By a comparison of the reference measurement and the degraded measurement of each tuning section in turn the positions of the mode jumps of the laser will be located at different currents. This can be seen in figure 4. It will be noted that the figures shown show output power of the laser and where there is a jump or discontinuity in the output power of the laser this denotes a mode jump.

By applying a transform on the degraded measurement the locations of mode jumps can be overlaid on the initial measurement. This is shown in the example of Figure 5 where the transform takes the following form:

$P_i(I_t)$ is the initial power measurement as a function of the tuning current

$P_d(I_t)$ is the degraded power measurement as a function of the tuning current

The mode jumps in each measurement can then be located by differentiation or some other techniques as will be apparent to those skilled in the art. This means that we find a set of currents (I_t) for both measurements where mode jumps occur

$(I_{f0}, I_{f1}, I_{f2}, I_{f3} \dots I_{fn})$

$(I_{s0}, I_{s1}, I_{s2}, I_{s3} \dots I_{sm})$

The transform (T) is such that

$(I_{f0}, I_{f1}, I_{f2}, I_{f3} \dots I_{fn}) = T((I_{s0}, I_{s1}, I_{s2}, I_{s3} \dots I_{sm}))$

In the example shown in Figure 5 the transform is $T(I_t) = a + bI_t$,

And where a and b are constants defining the amount of degradation that has occurred. As shown in Figure 5 the values of a and b are

5 a=0
b=.95

This corresponds to this tuning section requiring 5% more current to achieve the same mode jump in the laser and is
10 equivalent to a leakage current increasing in this laser section.

Though the example above shows a linear relationship in the transform T, other forms of this equation can be used
15 such as super-linear, n-dimension polynomial, exponential or otherwise.

One important distinction to mention with this invention is that as the other tuning sections have zero current
20 there will be no difference in the output of the laser due to degradation in these sections and each section can be taken independently and its degradation measured.

This can be explained by the following:

25 The aging rate for lasers in general follow the Arrhenius relationship according to the following equation:

$$AR \propto J^n \exp\left(\frac{e_a}{kT_j}\right)$$

where A.R is the aging rate

e_a is the activation energy

30 J is the current density in the material

k is Boltzmann constant

T_j is the junction temperature

n is the stress rate exponent

and where the laser is subjected to stress levels J and

35 T_j and where n is the stress rate exponent for the

current density. Each section can be described by this equation independently and each section will also have different values defining its aging rate. In the current invention the aging rate is zero for $J=0$ implying that
5 the aging of the device under operation (after time T) can be compared to the device characteristics at time 0, provided that $J_t=0$ for all t , where J_t is the current density for all tuning section of the laser. Therefore the aging of one section can be measured independently by
10 setting J (the current density, which is proportional to the current) to zero.

When the transform have been obtained for all tuning sections the lookup table of operating points can be
15 transformed using the inverse of the transform on each respective tuning section of the laser. Thereafter the new lookup table has been compensated for degradation in the laser.

20 In a similar embodiment of the above invention a comparator can be used to obtain the mode jumps of a laser. This is achieved by setting the comparator to transition between high and low when the output power or wavelength or etalon response moves above or below a
25 specific value. By setting this value to the median between two levels where there is a jump in the response corresponding to a mode jump in laser this can be detected with the comparator. The advantage of this is that it is fast and doesn't require many analogue to
30 digital conversions.

In another embodiment of the invention degradation can be measured while performing switches between two operating points from the set of operating points. These operating
35 points may be selected as the two operating points with the largest current difference between them in all

currents as this will cause the most severe thermal effect in the laser.

Then for one of the operating points, normally the one
5 with the highest currents, a set of operating points is
obtained in the tuning space about this point. Typically
this may be a set current that is added and subtracted to
each of the tuning currents in turn. E.g. for an SG-DBR
laser this would mean obtaining 6 operating points, two
10 for each of the three tuning sections.

The transitions from the first operating point to each of
the points about the second operating point are then
tested. If any of the transitions fail to achieve the
15 same wavelength as the second operating point that
transition is adjudged to have failed.

By observing which operating points have failed we obtain
a vector for adjustment of the second operating point. By
20 adjusting all the operating points in the table using
this vector the degradation in the device can be
compensated out of the performance of the laser.

Other embodiments of this invention include methods to
25 blank the output of the device while the above
measurements are being performed. In one embodiment the
laser may have a SOA (Semiconductor Optical Amplifier)
but coupled to the output of the laser. This section can
be negatively biased or otherwise to make it lossy and
30 hence reduce the output light from the laser. Other
sections such as EA (electro absorption) modulators can
also perform a similar effect. Also in another embodiment
the phase section or other tuning sections can be used as
a photo-detector to monitor the mode positions or output
35 characteristics of the laser while the other section
currents are varied. This means that if the output of the

laser is disabled through use of an SOA or otherwise the measurements can be performed therefore the output of the laser will not interfere with the system it may be connected to.

5

It will be appreciated that the present invention provides an efficient manner to effectively compensate for degradation in performance of a laser diode. Although it has been described with reference to an exemplary embodiment, it will be appreciated that it is not intended to limit the present specification in any manner except as may be necessary in the light of the appended claims.

10

15 The embodiments in the invention described with reference to the drawings comprise a computer apparatus and/or processes performed in a computer apparatus. However, the invention also extends to computer programs, particularly computer programs stored on or in a carrier adapted to bring the invention into practice. The program may be in the form of source code, object code, or a code intermediate source and object code, such as in partially compiled form or in any other form suitable for use in the implementation of the method according to the invention. The carrier may comprise a storage medium such as ROM, e.g. CD ROM, or magnetic recording medium, e.g. a floppy disk or hard disk. The carrier may be an electrical or optical signal which may be transmitted via an electrical or an optical cable or by radio or other means.

20
25
30

The words "comprises/comprising" and the words "having/including" when used herein with reference to the present invention are used to specify the presence of stated features, integers, steps or components but does not preclude the presence or addition of one or more

35

other features, integers, steps, components or groups thereof.

The invention is not limited to the embodiments
5 hereinbefore described but may be varied in both
construction and detail.

10

Claims

- 1) A method of measuring the degradation in a tunable
5 laser comprising the steps of:
- a. performing a first set of initial measurements
on the laser to provide a reference set of
measurements corresponding to the performance
of the laser when no degradation has occurred;
 - 10 b. performing a second set of measurements on the
laser where some degradation has occurred; and
 - c. effecting a comparison of the first and second
set of measurement so as to provide a measure
of the degradation in the laser.
- 15
- 2) The method as claimed in claim 1 wherein the first
set of initial measurements is provided by one or more
of the steps of:
- setting the gain current of the laser to a
20 specified predetermined value;
 - setting the tuning currents of the laser to
zero;
 - measuring the output power / etalon/ wavelength
of the laser while the current of one tuning
25 section is increased and while the currents in
all other tuning sections is set to zero; and
 - repeating the above measurement for all tuning
sections of the laser.
- 30
- 3) The method as claimed in claim 2 wherein the
predetermined specified valued of the gain current
selected is the average gain current of the operating
points in a lookup table corresponding to the laser.

4) The method claimed in any preceding claim wherein the second set of measurements is provided by one or more of the steps of:

5 setting the gain current of the laser to a
specified predetermined value, for example the
average gain current of the operating points in
the lookup table;
10 setting the tuning currents of the laser to zero;
measuring the output power / etalon/ wavelength of
the laser while the current of one tuning section
is increased and while the currents in all other
tuning sections is set to zero; and
15 repeating the above measurement for all tuning
sections of the laser.

15 5) The method as claimed in any preceding claim
wherein on comparison of the first set of measurements
with the second set of measurements by comparing
wavelength or etalon responses the degradation of the
20 device can be measured.

25 6) The method claimed in claim 1 where the positions of
mode jumps in the two sets of measurements are compared
and a transform is obtained where the mode jumps from
the second set of measurements can be transformed to
the same currents as the corresponding mode jumps as
determined from the first measurement.

30 7) The method as claimed in claim 6 further comprising
the step of converting the operating points of a
tunable laser by this transform to obtain a new set of
operating points where the new set of operating points
is compensated for degradation in the laser.

8) The method claimed in claim 1 wherein the second set of measurements is provided by one or more of the steps of:

5 locating a subset of mode jumps from the first measurement set; and
 re-measuring the region around each of these mode jumps in the same manner as the first set of measurements.

10 9) A method of compensating for a degradation of a laser diode comprising the steps of:

 monitoring transitions between two operating points of a laser while varying the currents of the second operating point;
15 determining when a transition from a first wavelength to an operating point about the second does not correspond to a wavelength of the second operating point and then applying a fail status to this transition; and
20 using the location of the nearest failed operating point about the second operating point to provide a vector of the degradation of the laser.

25 10) A method as claimed in claim 9 where the vector obtained for the degradation of the device can be used to adjust all the operating points of the laser to compensate for degradation in the laser.

30 11) A computer program comprising program instructions for causing a computer to perform the method of any one of claims 1 to 10.

 12) A computer program as claimed in claim 11 embodied on a record medium

35 13) A computer program as claimed in claim 11 embodied

on a carrier signal.

14) A computer program as claimed in claim 11 embodied
on a read-only memory.

5

10

15

20

25

30

35

1/3

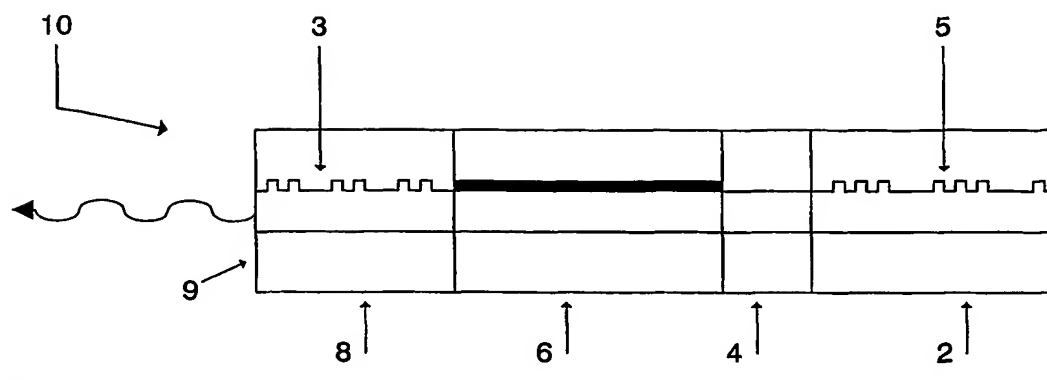


Figure 1

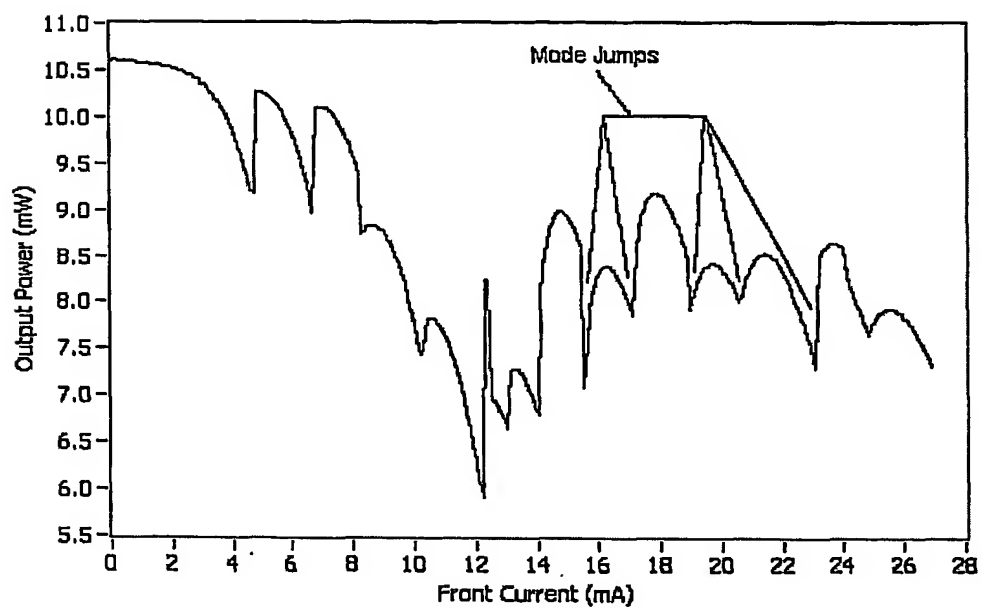


Figure 2

2/3

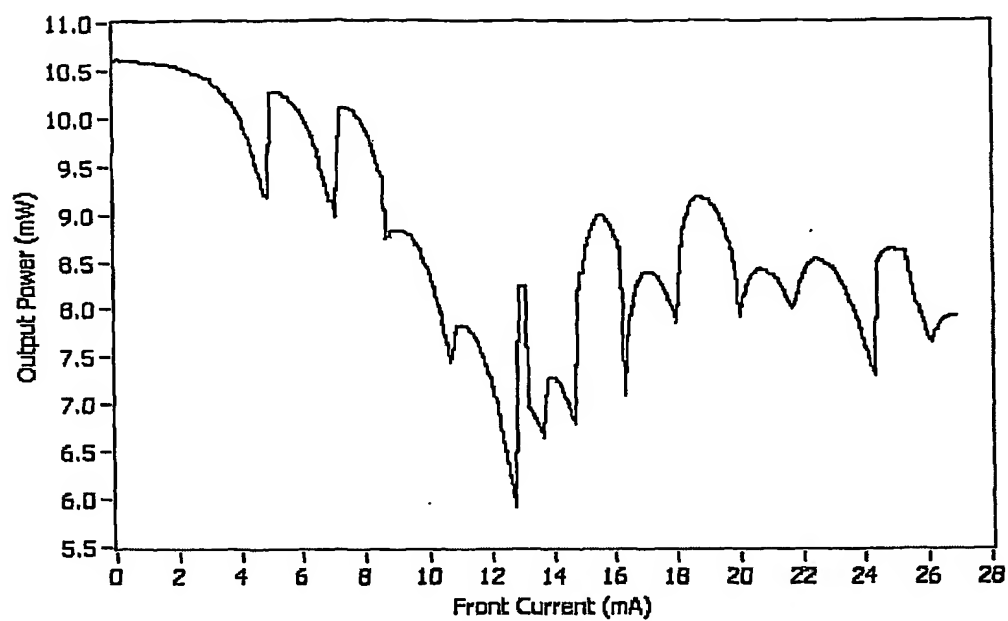


Figure 3

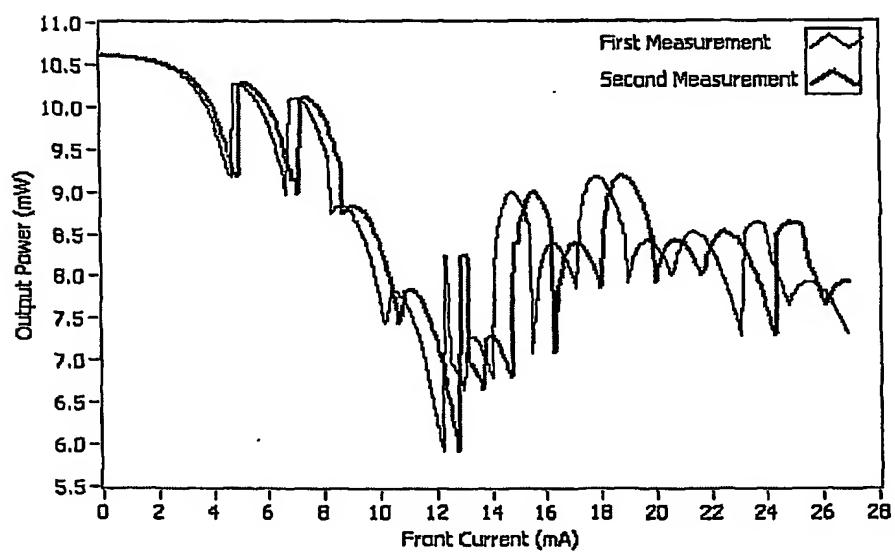


Figure 4

3/3

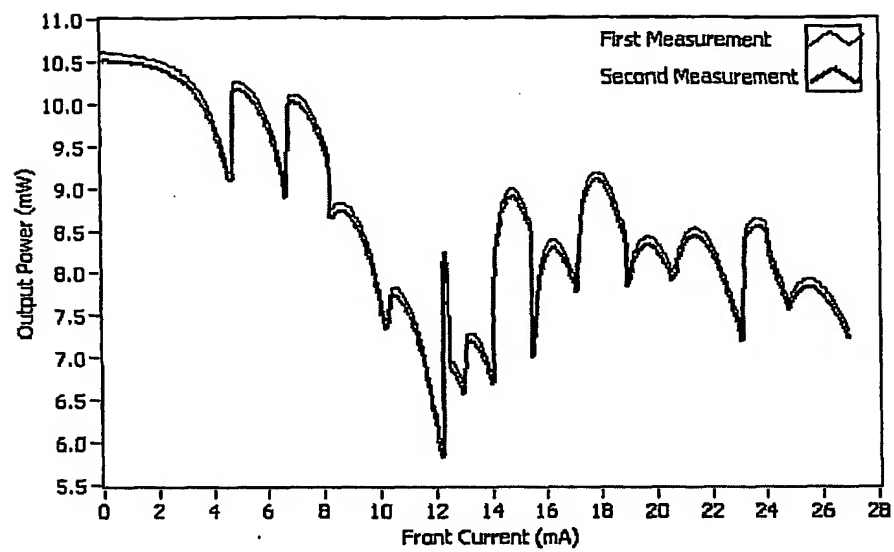


Figure 5

INTERNATIONAL SEARCH REPORT

International Patent No.

PCT/IE 03/00148

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 H01S5/068

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 H01S

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the International search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, IBM-TDB, INSPEC, COMPENDEX

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 01 76029 A (ALTITUN AB ; WESSTROEM JAN OLOF (SE)) 11 October 2001 (2001-10-11)	1
A	page 3, line 4-23 page 5, line 11-16 page 7, line 21 -page 8, line 32; figure 2	9
X	PATENT ABSTRACTS OF JAPAN vol. 011, no. 198 (E-519), 25 June 1987 (1987-06-25) & JP 62 025482 A (OLYMPUS OPTICAL CO LTD), 3 February 1987 (1987-02-03)	1
A	abstract --- -/-	9

☒ Further documents are listed in the continuation of box C.☒ Patent family members are listed in annex.

* Special categories of cited documents:

- *A* document defining the general state of the art which is not considered to be of particular relevance
- *E* earlier document but published on or after the international filing date
- *L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- *O* document referring to an oral disclosure, use, exhibition or other means
- *P* document published prior to the international filing date but later than the priority date claimed

- *T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- *X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- *Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
- *Z* document member of the same patent family

Date of the actual completion of the international search

20 February 2004

Date of mailing of the international search report

04/03/2004

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer

Gnugesser, H

INTERNATIONAL SEARCH REPORT

Inter...ation No
PCT/IE 03/00148

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with Indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 1 195 861 A (AGERE SYST OPTOELECTRONICS) 10 April 2002 (2002-04-10)	1
A	column 6, line 20 -column 8, line 4 column 12, line 54 -column 14, line 17; figures 6,7,15,16 ---	9
X	EP 0 512 541 A (FUJITSU LTD) 11 November 1992 (1992-11-11)	1
A	abstract ---	9
X	WO 99 40654 A (ALTITUN AB ;ANDERSSON LARS (SE); BROBERG BJOERN (SE)) 12 August 1999 (1999-08-12)	1
A	claims 1,9-11; figures 2,3 -----	9

INTERNATIONAL SEARCH REPORT

International Search Report
PCT/IE 03/00148

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
WO 0176029	A	11-10-2001	SE 518158 C2 AU 3961401 A SE 0001251 A WO 0176029 A1 US 2003118062 A1	03-09-2002 15-10-2001 06-10-2001 11-10-2001 26-06-2003
JP 62025482	A	03-02-1987	US 4747091 A	24-05-1988
EP 1195861	A	10-04-2002	EP 1195861 A2 JP 2002158400 A	10-04-2002 31-05-2002
EP 0512541	A	11-11-1992	JP 2546080 B2 JP 4334078 A DE 69213811 D1 DE 69213811 T2 DE 69230734 D1 DE 69230734 T2 EP 0512541 A2 EP 0669684 A2 KR 9606211 B1 US 5334826 A	23-10-1996 20-11-1992 24-10-1996 30-01-1997 06-04-2000 29-06-2000 11-11-1992 30-08-1995 09-05-1996 02-08-1994
WO 9940654	A	12-08-1999	SE 519081 C2 AU 2304699 A CA 2316820 A1 EP 1050088 A1 JP 2002503036 T SE 9800143 A WO 9940654 A1 US 6504856 B1	07-01-2003 23-08-1999 12-08-1999 08-11-2000 29-01-2002 22-07-1999 12-08-1999 07-01-2003